ALTERNATIVES TO LEAD-ACID BATTERIES

Lead-acid batteries are the most widely used rechargeable battery and principally serve two sectors: automotive and industrial. Designing green and sustainable battery systems is essential, so criteria such as life cycle, abundance of raw materials and electrode recycling are becoming crucial.

The main competitors to lead-acid batteries are nickel-cadmium and lithium-ion batteries. Nickel-cadmium has an established niche position and lithium-ion batteries are being promoted in the industrial market. Lithium-ion batteries will remain more expensive than lead-acid which will restrict their uptake.

ALTERNATIVES TO LEAD-ACID BATTERIES IN INDUSTRIAL APPLICATIONS

Nickel-Cadmium

Nickel-cadmium (Ni-Cd) batteries have been used for many years for industrial applications because they are very robust under conditions of mechanical and electrical abuse. The use of Ni-Cd cells for consumer applications is prohibited for environmental reasons in the EU because of concerns about the toxicity of Cd but the continued use for industrial types is permitted with strict requirements for collection at end-of-life. Ni-Cd has a substantially higher cost than lead-acid because of the high cost of Ni and Cd. It is likely that Ni-Cd will retain a niche position for the foreseeable future and it poses no threat to lead-acid batteries.

Nickel-Metal Hydride Batteries

Nickel-metal hydride (Ni-MH) batteries are constructed in a similar way to sintered Ni-Cd cells but instead of a Cd electrode they have a metal hydride. The cost is high because of the use of Ni and rare earth metals in the hydride store. They are widely used for consumer applications because they are not restricted in the same way as Ni-Cd cells. They are being used in large quantities for hybrid electric vehicles but they have very limited application as industrial batteries. They are not and will not become a threat to lead-acid batteries because of cost and also because Li-ion batteries have greater potential.

Nickel-Zinc Batteries

Nickel-zinc (Ni-Zn) batteries have a lower cost compared to Ni-MH. There have been many attempts to develop Ni-Zn batteries but they have not been successful because of the behaviour of the Zn electrode which restricts cycle life. There are a small number of companies developing Ni-Zn batteries who claim to have solutions to these problems including EnerSys. If these programmes are successful, Ni-Zn may take market share from Ni-MH for consumer applications and Ni-Cd for industrial applications but it will remain more expensive than lead-acid and will not be a threat.

Lithium-ion Batteries

Billions of lithium-ion cells are produced for portable electronics, but this is not sustainable as cobalt must be obtained from natural resources. Safety is a major concern for Li-ion cells. They have a high energy density and the organic electrolyte is flammable. Li-ion cells are used for consumer portable applications in very large numbers and increasingly for both hybrid electric vehicles and pure battery electric vehicles. They are offered for industrial applications both for standby and motive power by various suppliers, generally as a packaged system built from cells sourced externally. They are more expensive and will remain at a premium to lead-acid batteries but they do pose a threat to lead-acid batteries. They are also being deployed in demonstrator schemes for utility energy storage which is a large potential market for batteries of all types.

Sodium-Sulphur Batteries

Sodium-sulphur (Na-S) batteries have an energy density substantially higher than lead-acid batteries and they have a long cycle life. Safety is an issue and careful design is required to prevent cell failures from propagating. Na-S batteries are manufactured from cheap and plentiful raw materials but the manufacturing processes and the need for insulation, heating and thermal management make these batteries quite expensive. As a result, they have mainly been used in large installations for utility load levelling and are not used in applications normally served by lead-acid batteries for industrial service.

Sodium-Nickel Chloride Batteries

Energy density is high but lower than Na-S batteries and a long cycle life is achieved. The targeted markets are utility energy storage, telecommunications, electric vehicles and hybrid railway locomotives. There are demonstrator batteries installed for utility energy storage and limited deployment in other applications. This chemistry is not a mainstream competitor for lead-acid industrial batteries.

Flow Batteries

For utility energy storage flow batteries have some potential. There are various chemistries but they all have energy producing cells with remote storage of active materials and so batteries with very large capacities are possible. In practice, the batteries are complex and the materials are expensive but the claimed life is very long. To date only a small number of demonstrator systems have been installed and vanadium redox batteries (VRB) batteries are only suitable for utility energy storage because of the size of battery envisaged. Zinc-bromine ($Zn-Br_2$) batteries are another type of flow battery.

Comparison of Different Battery Systems

The table below compares the battery systems that are available for industrial applications.

System	Energy density, Wh/kg	Battery cost, $/kWh	Cycle life, 80%	Calendar life, Years
Lead-acid	40	150	1800	20
Ni-Cd	50	500	2000	20
Ni-MH	80	600	1500	10
Ni-Zn	60	450	300	5
Li-NCA	180	600	1800	7
LFP	150	400	2500	8
Na-S	110	500	4000	15
$Na-NiCl_2$	90	600	4000	20

ALTERNATIVES TO LEAD-ACID BATTERIES IN AUTOMOTIVE

Although automakers have made significant innovation and progress in alternative technologies, **lead-based batteries are still the only technologically viable mass-market option currently available for conventional vehicles,** as well as for start-stop and micro-hybrid vehicles. Alternative technologies would need to match traditional batteries in terms of reliability, safety, cost and other factors.

The following energy storage systems are used in hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and all-electric vehicles (EVs).

Lithium-Ion Batteries

Billions of lithium-ion cells are produced for portable electronics, but this is not sustainable as cobalt must be obtained from natural resources. In addition, there are safety concerns, as the presence of both combustible material and an oxidizing agent carries a risk of runaway reactions resulting in fires or explosions. Improvements in the electrolyte composition could make the chemistry safer, but accidents are mainly a result of fierce cost-cutting and attempts to cram more active material in the same volume, causing internal short-circuits. As a result, improvements in monitoring and management are essential if lithium-ion batteries are to fulfil their potential in the automotive market.

Lithium-ion batteries are currently used in most portable consumer electronics such as cell phones and laptops because of their high energy per unit mass relative to other electrical energy storage systems. They also have a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge. Most components of lithium-ion batteries can be recycled. Most of today's plug-in hybrid electric vehicles and all-electric vehicles use lithium-ion batteries, though the exact chemistry often varies from that of consumer electronics batteries. Research and development is ongoing to reduce cost, reduce the carbon footprint, and extend their useful life cycle. The demand for lithium could also be eased by recycling, which has already proved its value with lead–acid batteries. All these problems must be overcome if lithium batteries are to take their place as the batteries of the future

Nickel-Metal Hydride Batteries

Nickel-metal hydride batteries, used routinely in computer and medical equipment, offer reasonable specific energy and specific power capabilities. Nickel-metal hydride batteries have a much longer life cycle than lead-acid batteries and are safe and abuse tolerant. These batteries have been used successfully in all-electric vehicles and are widely used in hybrid electric vehicles. The main challenges with nickel-metal hydride batteries are their high cost, high self-discharge and heat generation at high temperatures, and the need to control hydrogen loss.

Ultracapacitors

Ultracapacitors can provide vehicles additional power during acceleration and hill climbing and help recover braking energy. They may also be useful as secondary energy-storage devices in electric drive vehicles because they help electrochemical batteries level load power.

Cost Comparison for Battery Chemistries Across Different Vehicle Classes

Vehicle Class	Battery Chemistry		
	Lead-acid	Nickel	Lithium-ion
Class 1 Conventional	50-150 €/kWh 6-18 €/kW	700-1400 €/kWh 90-180 €/Kw	600-1200 €/kWh 118-236 €/kW
Class 2 Hybrid	100-200 €/kWh 10-20 €/kW	800-1400 €/kWh 27-47 €/kW	800-1200 €/kWh 30-75 €/kW
Class 3 EV	100-250 €/kWh 10-25 €/kW	400-500 €/kWh 910-1140 €/kW	300-450 €/kWh 100-200 €/kW
Class 4 PHEV	(not provided)	(not provided)	800-1200 €/kWh 30-75 €/kW

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